Effects of root rot on the growth of balsam fir

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Received March 20, 1985[1]
Accepted June 4, 1985

WHITNEY, R. D., and G. B. MACDONALD. 1985. Effects of root rot on the growth of balsam fir. Can. J. For. Res. 15: 890–895.

Growth increments were compared on balsam fir (*Abies balsamea* (L.) Mill.) trees with varying amounts of decay on the stump (15 cm above ground) that originated from the roots. In 1612 trees, from 20 to 156 years of age on 139 plots across northern Ontario, the average height and radial increments over the last 3 years were 13.5 and 10.9% smaller, respectively, in trees with ground-level decay compared with trees having no decay at this level. Stand basal area was more useful than tree age as a stratification variable for revealing the effect of root rot on growth. Growth reductions were the smallest in trees with intermediate surrounding basal areas and in trees on drier or heavier textured soils.

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On a comparé la croissance de sapins baumiers (*Abies balsamea* (L.) Mill.) dont la souche (15 cm au-dessus du sol) était attaquée à divers degrés par des caries provenant des racines. Partant d'un échantillon total de 1612 arbres âgés de 20 à 156 ans et répartis dans 139 parcelles situées dans le nord de l'Ontario, on a trouvé que chez les arbres présentant de la carie au niveau de la souche, les accroissements moyens en hauteur et en diamètre pour les trois dernières années étaient, respectivement, de 13,5 à 10,9% inférieurs par rapport aux arbres exempts de caries à ce niveau. La surface terrière du peuplement s'est révélée une variable de stratification plus utile que l'âge des arbres pour faire voir l'effet des pourridiés sur la croissance. La perte de croissance était moins élevée chez les arbres se trouvant dans des peuplements dont la surface terrière était classée intermédiaire et chez les arbres poussant dans des sols plus secs ou à texture plus lourde.

Introduction

The recent intensification of forest management in Canada will no doubt result in an increased scrutiny of wood volume returns relative to the time and money invested. As efforts increase to maximize volume production, the effect of pathological factors on tree growth will concern forest managers more directly.

Whitney (1976) has shown that root rot is abundant in balsam fir (*Abies balsamea* (L.) Mill.), a species proportionately increasing on cutover land in Ontario (Yang and Fry 1981). A study was therefore conducted to determine the effect of root rot on the growth of balsam fir.

Methods

Upland balsam fir stands exceeding 75% fir by basal area and ranging from 20 to 156 years of age were sampled from 1971 to 1981 across northern Ontario (Fig. 1). Sections B.4, B.8, B.9, B.10, and B.11 of the Boreal Forest Region and sections L4*e*, L9, and L10 of the Great Lakes – St. Lawrence Forest Region (Rowe 1972) were sampled. Site regions 3W, 4W, 3D, 4E, and 5E (Hills 1961) were covered by the samples. The stands were free from major disturbances such as spruce budworm for at least 5 years prior to sampling and most were located on basal till soils of sandy loam texture. Within these stands, 139 plots ranging in size from 0.25 to 0.75 ha were established. Before sampling each plot, basal area by species was measured with a wedge prism. Soil moisture regime and texture class (Anonymous 1982) were determined from a soil pit dug on each plot.

A representative sample of 10–20 dominant or codominant fir was selected for analysis on each plot, providing a total sample of 1612 trees. The trees were felled and the percentage of cross-sectional area decayed at 15 cm above ground level was estimated (Fig. 2). A preliminary analysis of 1089 balsam fir at 109 locations indicated that decay and stain as seen at a height of 15 cm were reasonably well correlated ($r = 0.65$) with root decay and stain. For each tree, measurements were made of outside bark diameter at breast height (DBH), basal age, total height, and internode length for the most recent 3 years. Discs were removed from the breast-height level for laboratory analysis of radial growth, also for the most recent 3 years. We considered that the most recent period of increment would best reflect the effect of root decay on growth. A period of at least three growing seasons should be used to minimize the effect of yearly climatic fluctuations.

Samples of each decay type were cut from the butt area of each tree for isolation and identification of causal fungi. Four to 10 triangular wood chips, about 3 mm on each side, were removed aseptically from the rot samples and placed on sterile 1.25% malt and 2% agar in test tubes. After incubating for a maximum of 6 weeks, fungi were identified using standard keys (Nobles 1948) and a reference collection of cultures.

An Addo-X tree ring measuring and recording device was used to obtain radial increments from the average diameter (longest diameter plus diameter perpendicular to this, divided by 2) on each breast-height disc. Periodic radial increments (RI) and height increments (HI), both over the last 3 years, were calculated for each tree. Data were analyzed with the Tectronix 4052 computer system to calculate the increments, stratify the data, determine basic statistics, and perform regression analyses.

Results and discussion

The means and coefficients of variation were calculated for radial and height increments by ground-level decay (GLD) classes (Tables 1–4). The data were arbitrarily stratified to separate out the effects of tree age (Table 1), stand basal area (Table 2), soil moisture (Table 3), and soil texture (Table 4) on

[1]Revised manuscript received May 29, 1985.

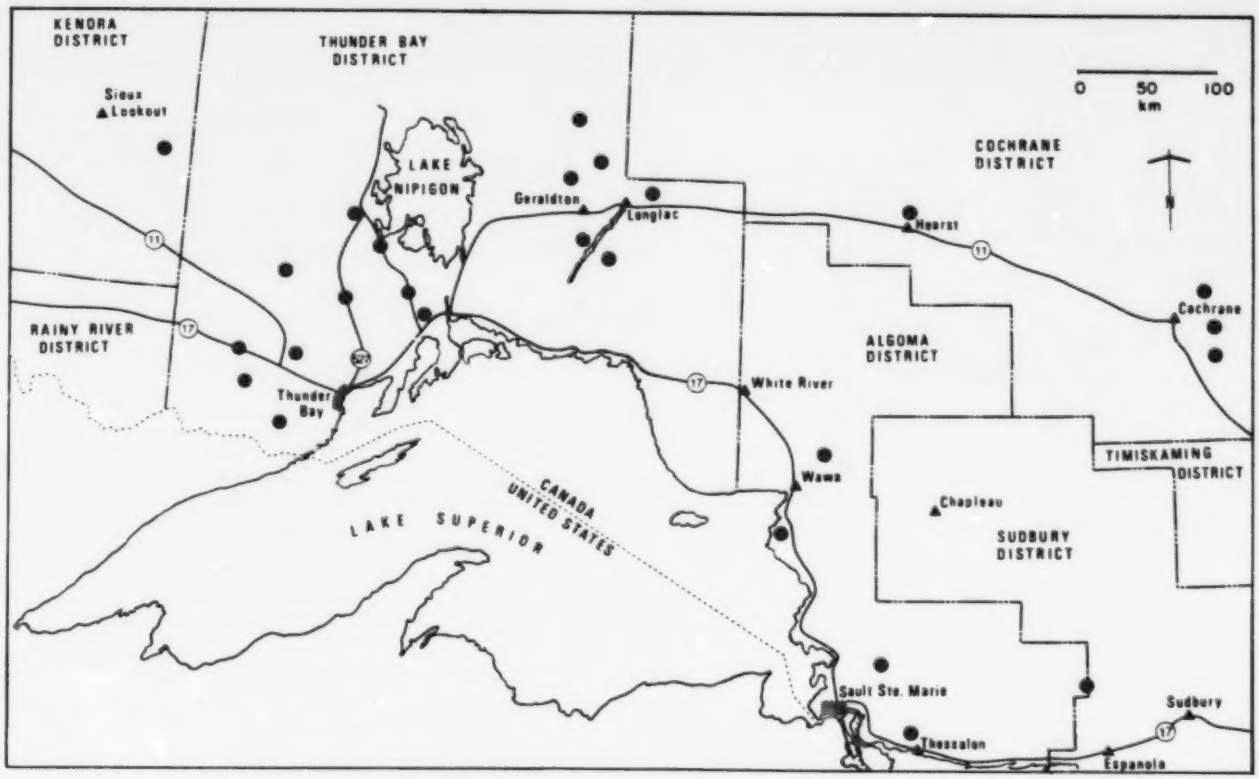

FIG. 1. Plot locations (●) in balsam fir root rot study. Each circle represents from 1 to 14 plots in the general area.

FIG. 2. A representative sample of ground-level decay (GLD) showing a brown cubical rot that occupies approximately 40% of the stump surface area.

the relationship between growth and GLD.

Even within these strata, only a small proportion of the growth variation could be explained by GLD linear regression analyses or curvilinear equations that included second- or third-degree polynomials. Other factors affecting tree growth such as stand composition, minor vegetation, climate, topography, etc., would have to be included in the analysis if higher proportions of the growth variation were to be accounted for. Growth trends could be seen within the various strata, however.

TABLE 1. Statistical summary for radial increment (RI) and height increment (HI) of balsam fir trees with and without root rot in various decay classes by three broad age groups in northern Ontario

Age-class (years)	Decay class at ground level (%)	No. of trees	RI (previous 3 years) Mean (mm)	RI CV[a] (%)	RI Difference from control (%)	HI (previous 3 years) Mean (cm)	HI CV[a] (%)	HI Difference from control (%)
20–54	0 (control)	148	4.8	43	0	98	31	0
	1–30	311	4.6	48	−4.2	95	34	−3.1
	31–60	88	4.8	45	0	93	31	−5.1
	≥61	19	4.8	52	0	96	35	−2.0
Total or weighted avg.[b]		418	4.7		−3.1	95.5		−3.5
55–79	0 (control)	94	3.4	50	0	70	42	0
	1–30	288	3.3	52	−2.9	69	37	−1.4
	31–60	99	3.5	52	2.9	70	41	0
	≥61	32	3.2	58	−5.9	61	31	−12.9
Total or weighted avg.[b]		419	3.4		−1.8	68.9		−1.9
80–156	0 (control)	44	2.8	62	0	59	30	0
	1–30	276	3.1	55	10.8	57	36	−3.4
	31–60	145	3.0	57	7.1	54	34	−8.5
	≥61	68	2.5	68	−10.8	53	36	−10.2
Total or weighted avg.[b]		489	3.0		6.7	55.8		−5.9
Grand total or weighted avg.[b]		1326	4.1		1.1	73.9		−4.4

[a]Coefficient of variation.
[b]Excluding controls; avg., average.

TABLE 2. Statistical summary for radial increment (RI) and height increment (HI) of balsam fir trees with and without root rot in various decay classes by three basal area classes in northern Ontario

Basal area class (m^2/ha)	Decay class at ground level (%)	No. of trees	RI (previous 3 years) Mean (mm)	RI CV[a] (%)	RI Difference from control (%)	HI (previous 3 years) Mean (cm)	HI CV[a] (%)	HI Difference from control (%)
0–29.9	0 (control)	80	4.8	51	0	93	39	0
	1–30	257	4.3	50	−10	83	43	−11
	31–60	98	4.4	51	−8	79	43	−15
	≥61	29	4.0	61	−17	73	45	−22
Total or weighted avg.[b]		384			−10.3			−12.7
30–34.9	0 (control)	102	3.7	47	0	75	43	0
	1–30	340	3.6	55	−3	73	39	−3
	31–60	126	3.5	58	−5	64	44	−15
	≥61	51	2.8	69	−24	62	44	−17
Total or weighted avg.[b]		517			−5.5			−7.1
≥35	0 (control)	104	3.7	49	0	83	33	
	1–30	278	3.2	54	−14	70	41	−16
	31–60	108	3.0	50	−19	67	36	−19
	≥61	39	2.7	61	−27	56	34	−33
Total or weighted avg.[b]		425			−16.2			−18.2
Grand total or weighted avg.[b]		1326			−10.3			−12.3

[a]Coefficient of variation.
[b]Excluding controls; avg., average.

TABLE 3. Statistical summary for radial increment (RI) and height increment (HI) of balsam fir trees with and without root rot in various decay classes by three soil moisture classes in northern Ontario

Soil moisture class[a]	Decay class at ground level (%)	RI (previous 3 years) No. of trees	Mean (mm)	CV[b] (%)	Difference from control (%)	HI (previous 3 years) No. of trees	Mean (cm)	CV[b] (%)	Difference from control (%)
0–1 (dry)	0 (control)	54	4.4	46	0	50	91	40	0
	1–30	208	4.2	49	−5	199	83	41	−9
	31–60	114	4.1	52	−7	112	76	40	−17
	≥61	36	3.6	57	−18	36	70	43	−23
Total or weighted avg.[c]		358			−6.9	347			−12.8
2–3 (moist)	0 (control)	164	4.1	48	0	155	85	36	0
	1–30	506	3.6	54	−12	473	73	38	−14
	31–60	166	3.5	52	−15	154	69	40	−19
	≥61	68	3.0	70	−27	59	61	43	−28
Total or weighted avg.[c]		740			−14.1	686			−16.4
4–7 (wet)	0 (control)	68	3.4	61	0	67	73	44	0
	1–30	161	3.2	61	−6	155	69	51	−6
	31–60	52	2.6	69	−24	50	55	47	−25
	≥61	15	2.1	63	−38	15	51	37	−30
Total or weighted avg.[c]		228			−12.0	220			−11.5
Grand total or weighted avg.[c]		1326			−11.7	1253			−14.5

[a]Anonymous 1982.
[b]Coefficient of variation.
[c]Excluding controls; avg., average.

TABLE 4. Statistical summary for radial increment (RI) and height increment (HI) of balsam fir trees with and without root rot in various decay classes by three soil texture classes in northern Ontario

Soil texture class[a]	Decay class at ground level (%)	RI (previous 3 years) No. of trees	Mean (mm)	CV[b] (%)	Difference from control (%)	HI (previous 3 years) No. of trees	Mean (cm)	CV[b] (%)	Difference from control (%)
1–3 (light)	0 (control)	81	4.6	43	0	78	96	36	0
	1–30	224	4.1	48	−11	215	85	38	−12
	31–60	93	4.3	51	−7	90	78	45	−19
	≥61	37	3.7	67	−20	36	72	43	−25
Total or weighted avg.[c]		354			−10.9	341			−15.2
4–8 (medium)	0 (control)	92	4.4	48	0	88	85	32	0
	1–30	325	3.9	56	−11	305	77	41	−9
	31–60	126	3.8	52	−14	119	70	36	−18
	≥61	48	3.1	55	−30	43	65	41	−24
Total or weighted avg.[c]		499			−13.6	467			−12.7
9–13 (heavy)	0 (control)	107	3.3	56	0	100	72	44	0
	1–30	309	3.2	55	−3	291	64	42	−11
	31–60	109	2.8	57	−15	103	61	42	−15
	≥61	34	2.5	78	−24	31	48	33	−33
Total or weighted avg.[c]		452			−7.5	425			−13.6
Grand total or weighted avg.[c]		1305			−10.7	1233			−13.7

[a]Anonymous 1982.
[b]Coefficient of variation.
[c]Excluding controls; avg., average.

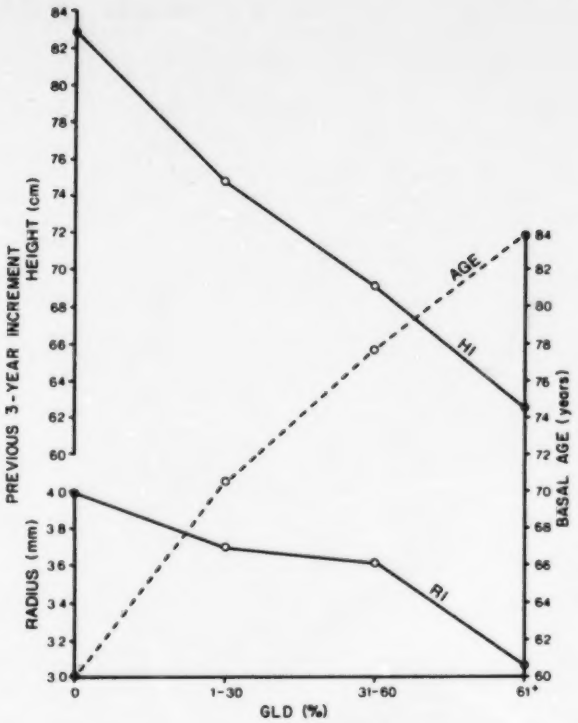

FIG. 3. Relationships between mean percent GLD and means of tree age, 3-year radial increment (RI), and 3-year height increment (HI).

Current increments, both RI and HI, were smaller in trees having GLD than in those having no GLD (Fig. 3). The more rapid reduction of HI compared with RI with increases in GLD, especially in the lower decay classes, indicates a greater sensitivity of HI than RI to root rot as represented by GLD. Radial growth reductions at a given time, however, may be more important for tree volume loss than HI reduction, because of the compounding of the radius function in the volume formula.

Percent decay tends to increase with the basal age of the trees (Fig. 3). However, stratifying samples by age-class, as is often done in disease studies, does not clarify the relationship between growth and GLD in balsam fir (Table 1). The shade tolerance of this species, which allows release following early prolonged suppression, may lead to rapid growth in trees that are heavily rotted from previous years, the release of the tree resulting in new roots that are sustaining the rapid growth. This tolerance may partly explain good growth in some heavily root-rotted trees found in this study (Table 1).

Because balsam fir can respond well to release after enduring long periods of suppression (Morris 1948), the growth of an individual tree may be affected more by the level of surrounding competition than by its chronological age. Therefore, arranging trees by basal area class allows the effect of other factors, such as root rot, to be more easily distinguished (Table 2).

Current growth of individual balsam fir trees was best where the basal area per hectare was smallest, but growth in all basal area classes was best where there was no GLD (Table 2). Trees in the highest GLD classes had the lowest growth rates, both RI and HI. Trees with more than 61% of stump cross section decayed (GLD) averaged 17–27% smaller RI and 17–33% smaller HI when compared with trees having no GLD. The average growth reductions in all trees having GLD, compared with those having none, were 10.3 and 12.3% of RI and HI, respectively (Table 2).

Stratification by other factors that affect tree growth, such as soil moisture (Table 3) and soil texture (Table 4), also allows the effects of GLD on growth rate to be seen. In all classes of soil moisture and soil texture, trees with the most GLD also had the greatest differences in current growth from the control trees (those with no GLD). When trees were stratified by soil moisture class or soil texture class, those having GLD averaged 10–11% smaller in current RI and 13–14% smaller in current HI than trees with no GLD. These are similar reductions to those seen by arranging data by basal area classes.

Severely decayed trees (those with ≥61% of GLD) have poor recent growth regardless of stand basal area, soil texture, or soil moisture class. However, least overall radial growth loss as a result of root rot was experienced in trees in the intermediate basal area class, lowest soil moisture class, and highest soil texture class. These findings suggest that when considering balsam fir, forest managers should strive for stands with intermediate basal areas growing on drier, heavier soils if growth reductions resulting from root rot are to be minimized.

Root rot losses in the form of dead trees, premature windfall, and butt cull are more easily diagnosed and measured and, hence, are given more recognition than growth losses (Whitney 1976). However, losses of growth resulting from root destruction reduce the size of the growing stock and have a cumulative effect that can also be significant.

The high proportion of GLD (60–70% of root wood decayed) required to effect a reduction in tree growth (Whitney 1962) is probably a reflection of the nature of root rot as well as the magnitude of the tree root system. Much of the root rot is located in the central wood of the roots and stump where little effect on vital tissues would occur. Also, extensive root systems would still have lengthy, functional roots even when 50–60% of the roots were attacked and debilitated or killed. The ability of white spruce (*Picea glauca* (Moench) Voss) trees to maintain an established level of diameter growth even when roots were heavily attacked by *Polyporus tomentosus* Fr. was indicated in Saskatchewan (Whitney 1962). Similarly, Dubreuil (1981) found that Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) often showed no crown symptoms when severely attacked by *Phaeolus schweinitzii* (Fr.) Pat.

Twenty-one root-rotting fungi were identified from roots of the trees in this study. *Armillaria mellea* (Vahl ex Fr.) Karst. was by far the most frequently isolated fungus, followed in order of frequency by *Scytinostroma galactinum* (Fr.) Donk, *Coniophora puteana* (Schum. ex Fr.) Karst., *Odontia bicolor* (Alb. and Schw. ex Fr.) Quél., and *Haematostereum sanguinolentum* (Alb. and Schw. ex Fr.) Powzar. The others occurred in less than 4% of the trees. Growth rates could not be related to individual fungi because of the low numbers of trees when stratification for other factors was applied.

Acknowledgments

Full acknowledgment is extended to members and former members of the Ontario Ministry of Natural Resources, Site Classification Section, Maple, Ont., especially G. Pierpoint and J. R. M. Williams, for classifying sites on 109 of the plots. The authors are also indebted to B. E. Smith, R. J. Sajan, and

W. E. Britnell, Great Lakes Forest Research Centre, for root rot diagnosis and culturing of causal fungi, and to R. R. Forslund, Northern Forest Research Unit, Ontario Ministry of Natural Resources, for statistical analyses.

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